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Effects of Plutonium Quality on Critical Mass

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Introduction

Plutonium quality is an important measure for the proliferation-resistance of a nuclear energy system. Degraded plutonium quality decreases its attractiveness for use as nuclear weapons. Civil plutonium discharged from a nuclear reactor with high burn-up and separated from reprocessing has a composition very much different from that of weapons grade (WG). This reactor-grade (RG) plutonium consists of higher content of heat producing isotopes (e.g., ^{238}Pu) and spontaneous fissionable isotopes (^{240}Pu, ^{242}Pu) which can significantly complicate its use as nuclear weapons materials.

Proliferation attributes of plutonium discharged from light-water reactors (LWRs) with various burn-up and cooling times had been examined[1,2]. These include critical mass (kg), heat generation (W/kg), spontaneous neutron emission (n/s/kg), and inherent radiation barriers (Sv/h). The focus of these previous studies was on RG plutonium from spent LWR fuel. The enrichment (defined as (^{239}Pu + ^{241}Pu)/Total Pu) of LWR-grade plutonium is about 70% depending on the discharged burn-up (in GWD/t) and decay time (in years). For WG plutonium, the enrichment is ~94%. The bare (unreflected) spherical critical masses of the metallic plutonium (density of ~19.6 g/cc) from LWR spent fuel were calculated. They were different from that of WG plutonium by only about 50%. The degrees of difficulty of weapons-usability (as measured by the heat generation, and spontaneous neutron emission) of the total RG-plutonium were also calculated. They showed an increase by a factor of about 6 and 12 as compared to those of WG plutonium, for heat generation and spontaneous neutron emission, respectively. This study extends the plutonium quality to include those discharged from different types of reactors, some with different burn-ups, and examines the effect of plutonium quality on the critical mass.

Plutonium Quality from Different Fuel Cycles

Plutonium from deep-burn reactors (e.g., very high burn-up, or those fuelled with inert matrix fuel) may contain isotopic compositions unfavorable for weapons-use. Table 1 lists the quality of various types of plutonium, from weapons-grade to different reactor-grades.

Table 1. Plutonium Quality of Different Fuel Cycles

	^{238}Pu (%)	^{240}Pu/^{239}Pu	Plutonium Enrichment (wt %)*
Weapons[3]	0.01	0.062	93.9
Magnox[4]	0.2	0.231	81.4
VVER-440[5]	0.9	0.361	73.0
LWR[4]	1.5	0.379	71.5
LWR/MOX[6]	3.5	0.585	61.1
Candu-NU[7] (8.3 GWd/t)	--	0.440	61.1
Candu-MOX[7] (17.1 GWd/t)	--	0.598	64.0
MHTGR[8] (w/W-Pu)	1. 8	0.585	62.9
MHTGR[8] (deep Pu burn)	1.0	1.058	42.8
MHTGR[8] (deep Pu burn) w/30-y decay	1.0	1.058	14.4
LMFBR[6], core	0.08	0.432	70.1
blanket	0.02	0.050	95.3

*Note: (^{239}Pu + ^{241}Pu) /Total Plutonium, in some cases the plutonium may contain Am, Np, and U etc.

The bare (unreflected) spherical critical masses of these metallic plutonium (density of ~19.6%) were calculated by using the computer code MCNP5 and plotted in Figure 1 as function of enrichment, together with the bare spherical ^{235}U critical mass obtained from reference 9. For RG plutonium from most of the currently operating reactors (including those fuelled with MOX fuel), their enrichment varies from 60 to 80%, and their bare critical masses vary from a few % to about 50% higher than that of WG plutonium. In the case of plutonium discharged from the blanket of a LMFBR, its quality is higher than that of WG, and hence, a slightly smaller critical mass.

For a MHTGR operated in a deep-plutonium-burn cycle, the plutonium enrichment decreases to about 42%, and the bare critical mass increase by more than 2-fold of that of WG. The enrichment of this plutonium will decrease to ~14% after 300 year due to the decay of ^{241}Pu, and the bare critical mass will increase by more than 4-fold of that of WG.

Further decay will degrade the plutonium quality to ~7% after 300 years, and the bare critical mass increase to 4.6 times of that of WG. A long-term decay (e.g., ~100,000 years) when ^{239}Pu is at ~1% enrichment, the bare critical mass will be asymptotically approaching 90 kg (9-fold of that of WG), and controlled by the bare critical mass of ^{242}Pu.

The degrees of difficulty of weapons-usability (as measured by the heat generation, and spontaneous neutron emission) of the total plutonium with low enrichment (as depicted by those with deep-plutonium-burn) will increase by a factor of about 20 and 40, respectively.

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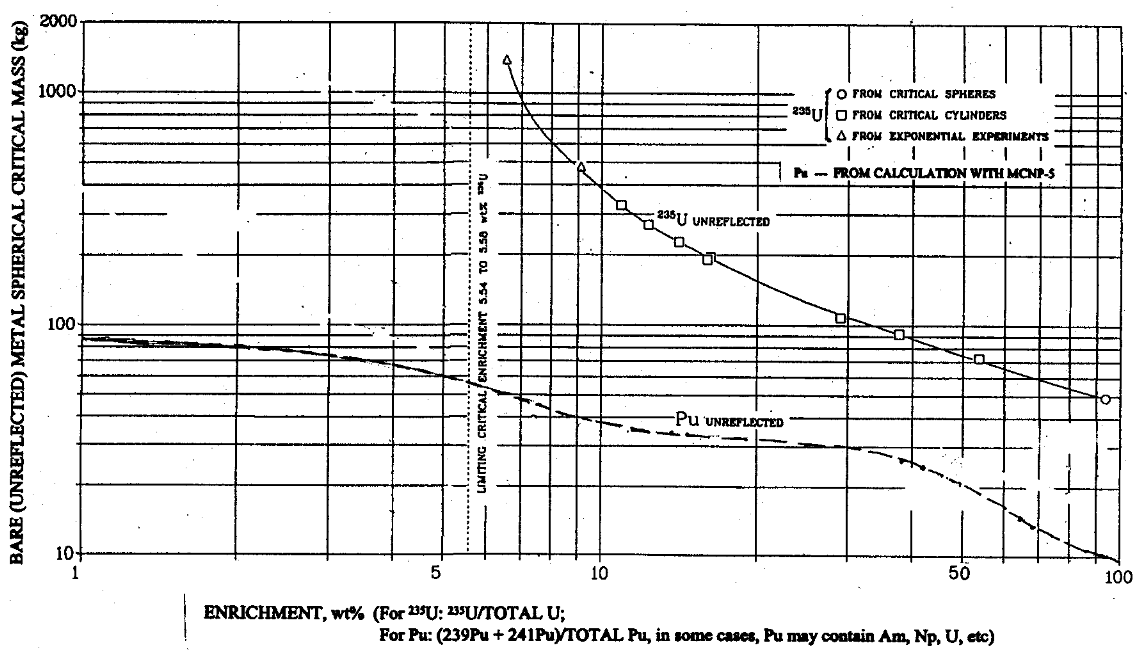
Figure 1. Bare (Unreflected) Metal Spherical Critical Mass of ^{235}U and Pu



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